Effect of Sucrose Octanoate on Survival of Nymphal and Adult *Diaphorina citri* (Homoptera: Psyllidae)

C. L. MCKENZIE[1] AND GARY J. PUTERKA[2]

J. Econ. Entomol. 97(3): 970–975 (2004)

ABSTRACT Asian citrus psylla, *Diaphorina citri* Kuwayama (Homoptera: Psyllidae) was detected for the first time in the United States near Delray Beach, FL, on 2 June 1998 and is continuing to spread and multiply throughout southern Florida. This psyllid is the vector of *Liberobacter asiaticum*, a phloem-limited bacterium that causes citrus greening disease. This pathogen has not been found in the Western Hemisphere to date. Furthermore, high infestation levels of *D. citri* can impact citrus plant health, fruit quality, or yield. Replicated laboratory and spray booth bioassays were conducted to determine the insecticidal activity of a synthetic analog of natural sugar esters found in leaf trichomes of wild tobacco, *Nicotiana gossei* Domin, to nymphal and adult *D. citri*. Field trials were initiated in Fort Pierce, FL, in 2000 to determine activity of the sugar ester formulation (sucrose octanoate) on *D. citri* and other citrus pests, including immature Asian citrus leafminer, *Phyllocnistis citrella* Stainton and mites. Sucrose octanoate rates tested ranged from 400 to 8,000 ppm (0.1–2% formulated product). Our data suggest that both nymphal and adult *D. citri* as well as the mite complex tested would be equally controlled to levels of >90% at the higher concentrations of sucrose octanoate and that good coverage is key to efficacy.

KEY WORDS Asian citrus psylla, Asian citrus leafminer, mites, sucrose octanoate, sugar ester

THE ASIAN CITRUS PSYLLA *Diaphorina citri* Kuwayama, is the primary vector of the plant pathogen, *Liberobacter asiaticum.* This phloem-limited, Gram-negative bacterium-like organism causes citrus greening disease (also known as Huanglungbin or Likubin) (Catling 1970, Bové and Garnier 1994). The greening pathogen is also readily transmitted by grafting and propagating with infected plant material and is lethal to most commercial citrus cultivars (Gottwald et al. 1989). Greening is one of the most devastating citrus diseases in Asia and Africa (Aubert 1993), but the pathogen has not been found in the Western Hemisphere to date. However, *D. citri* was detected for the first time in the United States near Delray Beach, FL, in the summer of 1998 and has continued to spread and multiply throughout southern Florida (Knapp et al. 1998). *D. citri* is a serious threat to the Florida citrus industry if the pathogen that causes citrus greening disease becomes introduced or should *D. citri* be found to vector other diseases of citrus. Moreover, high infestation levels of *D. citri* can impact citrus plant health, fruit quality, or yield.

Florida has instituted successful biological control programs in citrus to control various mites and scale insects (Muma 1955; Clancy et al. 1963; Selhime et al. 1969; Debach and Rose 1976; Hart et al. 1978; Dowell et al. 1979; Nguyen and Sailor 1979; Nguyen 1986, 1987, 1988; Sailor et al. 1984; Glenn and Baranowski 1987; Thompson 1989; Browning 1990; Caceres and Childers 1991; Tefertiller et al. 1991), due in part to the stabilization of the grove. Pest control strategies that use harsh insecticides as the first line of defense against *D. citri* and other citrus pests could lead to the disruption of their natural enemies. In addition, indiscriminate use of pesticides often results in the development of resistance and control failure. Alternative chemistry that is safe for the beneficial insect complex, yet is selectively effective against the target pest, is a desirable component in citrus integrated pest management programs where most pests have been successfully controlled by their natural enemies. Sugar esters are of great interest because they have been found to be relatively nontoxic to key predators and parasitoids of many citrus pests (Michaud and McKenzie 2004).

Sugar esters are a new class of insecticidal compounds that seem to fit these criteria. Sucrose esters naturally occur in plants, are benign to the environment, and are being commercially synthesized for use in the food industry (Chortyk et al. 1996). Natural and synthetic sugar esters have been shown to be effective biorationals with insecticidal activity against a range of insect species. Soft-bodied arthropods, including

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

[1] USDA–ARS, U.S. Horticultural Research Laboratory, 2001 South Rock Rd., Fort Pierce, FL 34945.

[2] USDA–ARS, Appalachian Fruit Research Station, 45 Wiltshire Rd., Kearneysville, WV 25430.

Table 1. Toxicity of sucrose octanoate 1 DAT to immature and adult *D. citri* by using a petri dish bioassay with a detached leaf substrate

Developmental stage	*n*	Slope ± SE	LC_{50}[a] (95% FL)	LC_{90}[a] (95% FL)
Small nymph	250	1.48 ± 0.37	120a (24–240)	920a (640–1,640)
Large nymph	190	4.01 ± 0.43	920a (120–1,640)	1,960a (960–5,120)
Adult	387	3.71 ± 0.42	2,720b (2,480–3,040)	6,080b (5,160–7,800)

Means within columns followed by the same letter are not significantly different (95% fiducial limit [FL]).

[a] LC values expressed in ppm active ingredient of commercially formulated sucrose octanoate; five replications with seven concentrations.

mites, lepidopteran larvae, aphids, whiteflies, and psyllids experience rapid knock down after contact (Parr and Thurston 1968, Neal et al. 1994, Puterka and Severson 1995, Liu et al. 1996). In addition, mites (Neal et al. 1994), whiteflies (Liu and Stansly 1995), and leafminers (Hawthorne et al. 1992) have demonstrated ovipositional and feeding deterrence to sugar esters. Although the mode of action is unknown, it has been suggested that two primary modes of action against pear psylla, *Cacopsylla pyricola* Foerster, are possible: desiccation by alterations in the insect cuticle or suffocation by the sugar ester solution (Puterka et al. 2003).

The primary objective of this study was to determine the dosage–mortality relationships of sucrose octanoate (α-D, glucopyranoside, β-D-fructofuranosyl octanoate), a synthetic analog of natural sugar esters found in leaf trichomes of wild tobacco, *Nicotiana gossei* Domin, to nymphal and adult *D. citri* via laboratory bioassays and spray booth experiments. Additionally we wanted to establish sucrose octanoate efficacy against this and other key mite and insect pests in field trials on citrus.

Materials and Methods

Insect Source and Rearing. *D. citri* were collected in 1999 from field populations infesting citrus at the United States Horticultural Research Laboratory experimental farm at Fort Pierce, FL, and used to start a laboratory colony. All stages of pysllid (egg, nymph, and adult) were reared on orange jasmine, *Murraya paniculata* (L.) Jack, and housed in large screened Plexiglas cages located in air-conditioned greenhouses with ambient light and humidity. Temperatures fluctuated between day and night highs of 29.4 and 26.7°C, respectively, with an overall low of 23.9°C.

Biorationals. Sucrose octanoate, a synthetic analog of natural sugar esters, was provided by AVACHEM (AVA Chemical Ventures, L.L.C., Portsmouth, NH) as a 40% (AI) formulation and was used in all bioassays, spray booth experiments, and field trials. M-Pede (Dow AgroSciences, L.L.C., San Diego, CA), a common insecticidal soap, and AGRI-50 (Cal-Agri Products, L.L.C., Los Angeles, CA), a nontoxic, food-safe insecticide, were used for efficacy comparison to sucrose octanoate in field trials.

Laboratory Bioassays. Sucrose octanoate solutions were prepared in seven concentrations of 400–8,000 ppm (0.1–2.0% formulated product) in double distilled H_2O (ddH_2O) plus a ddH_2O control. The bioassay consisted of one sterilized *Citrus sinensis* (L.) Osbeck leaf placed in a standard plastic petri dish that contained two sterile pieces of 7.0-cm Whatman No. 3 filter paper dipped in sterile ddH_2O. Concentrations were applied to *D. citri* nymphs or adults ($n = 15–20$) by using a petri dish spray device according to Puterka and Severson (1995). Each concentration was replicated five times, and bioassays were repeated three times.

Whole-plant bioassays were also conducted on *D. citri* nymphs to obtain dosage–mortality relationships under more natural conditions. Six-month-old orange jasmine seedlings in cone tubes were exposed to *D. citri* adults for 6 d. Plants were removed and held for an additional 5 d to allow nymphs to hatch and develop. On average, each plant was infested with 75 nymphs. Sucrose octanoate solutions were prepared in six concentrations of 800–8,000 ppm (0.2–2.0% formulated product) in H_2O plus a H_2O control and applied to infested plants with a spray booth (R&D Sprayers, Opelousas, LA). The spray booth was equipped with a single TJ nozzle operated at 61 psi to deliver 795 L/ha. Each concentration was replicated four times, and experiments were repeated three times. Mortalities were determined 24 h after treatment by examining each leaf of the treated plants for number of alive and dead small (first and second instar) and large (third and fourth instar) *D. citri* nymphs.

Field Trials. Three field trials were conducted at USHRL experimental farm at Fort Pierce, FL, to determine the effectiveness of sucrose octanoate against natural populations of *D. citri* under field conditions. Three-year-old ‘Ortanique’ Tangor, *Citrus sinensis* (L.) Osbeck × *Citrus reticulata* Blanco, trees were used in trials 1 and 2, and 2-yr-old ‘Sun shu sha’ *Citrus sinensis* (L.) Osbeck rootstock trees were used in trial 3. All treatments were arranged in a randomized complete block design with eight replications in trial 1, five replications in trial 2, and four replications in trial 3. Each replication contained three trees in trials 1 and 2, and five trees in trial 3. In trial 1, treatments were applied with a CO_2 backpack sprayer equipped with 50.8-cm boom and two TX18 hollow cone nozzles calibrated at 38 psi to deliver 125 ml per tree, and treatments were evaluated 1, 4, and 7 days after treatment (DAT). In an effort to obtain more complete tree coverage, trials 2 and 3 were applied with a CO_2 backpack sprayer equipped with a single TX18 hollow cone nozzle calibrated at 50 psi to deliver 200 ml (trial 2) and 250 ml (trial 3) per tree. Trial 2 was designed to evaluate Asian citrus leafminer, *Phyllocnistis citrella* Stainton mortality that compared a higher rate of su-

Table 2. Toxicity of sucrose octanoate 1 DAT to immature *D. citri* by using a spray booth with a whole-plant substrate

Nymph	n	Slope ± SE	LC_{50}[a] (95% FL)	LC_{90}[a] (95% FL)
Small	349	1.99 ± 0.35	1,040a (720–1,280)	4,600a (3,440–7,800)
Large	163	2.22 ± 0.56	1,520a (800–2,040)	5,760a (4,000–14,200)
Total nymph	530	1.97 ± 0.26	1,160a (880–1,400)	5,120a (4,080–7,360)

Means within columns followed by the same letter are not significantly different (95% fiducial limit [FL]).
[a] LC values expressed in ppm active ingredient of commercially formulated sucrose octanoate; four replications with seven concentrations.

crose octanoate (8,000 ppm) to the labeled use rate of M-Pede soap [2% (vol:vol) solution = 9,800 ppm], although *D. citri* and mite data were also taken. Treatments were evaluated 1 and 4 DAT in trial 2. Trial three was designed to evaluate the impact of two applications of sucrose octanoate in comparison to standard label rates of two biorational soap materials, 2% M-Pede (9,800 ppm), and 0.5% Agri-50 (50 ppm), for the control of *D. citri.* Treatments were evaluated 1, 4, and 7 d after the first application (DAT1) and 1, 4, 7, 10, 14, and 20 d after the second application (DAT2). Other citrus pests that were evaluated included *P. citrella* and a mite complex (common Texas citrus mite, red spider mite, and rust mite). Data taken from these studies included the number of *D. citri* adults per tree visible in a 2-min period and counts of *D. citri* eggs, small and large *D. citri* nymphs, mites and citrus leafminer larvae and pupae (trial 2) per 7.6-cm fresh flush terminal. Leaves infested with citrus leafminer larvae and pupae from the 7.6-cm fresh flush terminals were probed to determine whether they were dead or alive.

Statistics. Dosage–mortality relationships of sucrose octanoate to *D. citri* were evaluated by probit analysis (Sparks and Sparks 1987). Differences between LC_{50} values among life stages of *D. citri* were determined by failure of fudicial limits to overlap. Mortality data from the spray booth experiments were subjected to an analysis of variance (ANOVA). Mortality comparisons among different nymphal sizes in response to sucrose octanoate concentration were made using ANOVA and Ryan–Einot–Gabriel–Welsch multiple-range test (REGWQ) at $\alpha = 0.05$ (SAS Institute 2000). Field data were analyzed by the General Linear Models (GLM) procedure, and differences among treatment means were determined by Ryan–Einot–Gabriel–Welsch multiple range test (REGWQ) at $\alpha = 0.05$ (SAS Institute 2000).

Results and Discussion

Laboratory Bioassays. Sucrose octanoate showed higher toxicity to small and large *D. citri* nymphs, compared with adult *D. citri* by using the detached leaf petri dish bioassay (Table 1). Lethal concentration (LC) values were not significantly different between small and large nymphs. The LC_{50} and LC_{90} values for adult *D. citri* were ≈3 times greater than for nymphs, indicating that adults are less susceptible to sucrose octanoate than nymphs.

When sucrose octanoate was evaluated using a whole-plant bioassay and applied within a spray booth, LC values for small and large nymphs did not significantly differ (Table 2). Furthermore, LC_{50} and LC_{90} values were considerably higher for nymphs using the whole-plant bioassay. The higher sugar ester concentrations that were required to produce lethal concentration values for nymphs in the whole-plant bioassay may be due to less spreading on leaf surfaces, which is a factor that can affect sugar ester performance on plants (Puterka et al. 2003). The whole-plant bioassay produced LC_{50} and LC_{90} values for *D. citri* that were comparable with those that resulted in detached leaf bioassays for *Cacopsylla pyricola* Foerster (Puterka et al. 2003). Mortalities were significantly different among sucrose octanoate concentrations one DAT for small ($F = 15.43$; df = 6, 16; $P < 0.0001$) and large ($F = 25.58$; df = 6,18; $P < 0.0001$) nymphs, ranging from 51 to 100% and from 30 to 96% for small and large nymphs, respectively (Table 3).

Field Trials. *D. citri* populations were moderately high when the first field trial was initiated in the spring of 2000 with averages of 24 adults per 2-min tree count, six small nymphs, and four large nymphs per 7.6-cm fresh flush terminal. *D. citri* eggs averaged four per 7.6-cm fresh flush terminal. The number of *D. citri* life stages within each treatment did not differ over time ($P > 0.05$), thus psylla numbers were averaged over the 1-, 3-, and 7-d sample periods (Table 4). All treatments significantly reduced citrus psylla nymphs and adults compared with the untreated control ($P > 0.05$). However, there were no significant differences ($P > 0.05$) in egg and small and large nymph numbers in response to increasing sucrose octanoate concentrations from 1,600 to 4,000 ppm. Egg counts reveal a slight reduction in *D. citri* oviposition for the lower

Table 3. *D. citri* nymphal mortality for sucrose octanoate 1 DAT by using a spray booth with a whole-plant substrate

Sucrose octanoate conc.[a]	% Small nymph Mortality ± SE	% Large nymph Mortality ± SE
8,000	100.0 ± 0.00a	96.4 ± 3.57a
4,000	88.2 ± 11.76ab	90.1 ± 5.76a
3,200	86.8 ± 4.35ab	76.0 ± 5.49ab
2,400	71.7 ± 5.26ab	60.1 ± 5.14b
1,600	71.0 ± 7.21ab	51.6 ± 7.62bc
800	50.9 ± 17.16b	29.8 ± 11.72c
Control	0.0 ± 0.00c	0.0 ± 0.00d

Means within columns followed by the same lowercase letter are not significantly different ($P > 0.05$, REGWQ).

Spray booth was equipped with a single TJ nozzle operated at 61 psi to deliver 85 gal/acre.

[a] Concentration expressed in ppm active ingredient of commercially formulated sucrose octanoate.

Table 4. Field trial 1. Mean number of *D. citri* and citrus mite averaged over sample dates 1, 3, and 7 d after treatment (Trt) in treated and untreated Tangor citrus, St. Lucie County, Fort Pierce, FL

Treatment	Rate[a] (ppm)	Egg ± SE (% reduction)	Small nymph ± SE (% reduction)	Large nymph ± SE (% reduction)	Adult ± SE (% reduction)	Mites ± SE (% reduction)
Sucrose octanaote	1600	1.5 ± 0.5b (91)	0.8 ± 0.2b (95)	1.1 ± 0.3b (84)	12.2 ± 1.1bc (55)	0.6 ± 0.1b (95)
Sucrose octanoate	2400	1.9 ± 1.0b (89)	1.5 ± 0.6b (90)	0.8 ± 0.2b (88)	8.5 ± 0.9c (69)	1.0 ± 0.3b (91)
Sucrose octanaote	3200	5.0 ± 2.5ab (71)	2.0 ± 0.6b (88)	0.9 ± 0.4b (87)	7.8 ± 0.7c (71)	0.6 ± 0.3b (95)
Sucrose octanoate	4000	9.1 ± 2.9ab (47)	2.7 ± 0.8b (82)	1.7 ± 0.3b (75)	9.4 ± 0.9bc (65)	1.8 ± 0.7b (84)
M-Pede	9800	10.0 ± 4.1ab (42)	3.8 ± 1.4b (75)	1.4 ± 0.3b (80)	13.8 ± 1.1b (49)	1.4 ± 0.4b (88)
Untreated		17.1 ± 5.6a	15.2 ± 2.7a	6.9 ± 1.1a	27.2 ± 2.5a	11.2 ± 1.8a
Trt* date		$F = 1.87$	$F = 0.62$	$F = 0.16$	$F = 0.99$	$F = 1.18$
		df = 5,410	df = 5,410	df = 5,410	df = 5,315	df = 5,410
		$P = <.0987$	$P = <.6842$	$P = <.9773$	$P = <.4246$	$P = <.3197$
Trt		$F = 3.29$	$F = 16.19$	$F = 20.05$	$F = 34.95$	$F = 27.46$
		df = 5,410	df = 5,410	df = 5,410	df = 5,315	df = 5,410
		$P = <.0064$	$P = <.0001$	$P = <.0001$	$P = <.0001$	$P = <.0001$

Means within columns followed by the same lowercase letter are not significantly different ($P > 0.05$, REGWQ).
[a] Rate expressed in ppm active ingredient of commercially formulated product.

sucrose octanoate concentrations in comparison with the control ($F = 3.29$; df = 5, 410; $P < 0.006$), but overall sugar esters and insecticidal soaps had little effect on oviposition. Higher reductions of nymphs surviving sugar ester treatments occurred in the field trial than in the whole-plant bioassay; however, the field trial corresponded well to the results from the petri dish bioassay. Adults were less affected by the sucrose octanoate treatments than the nymphs, but field data indicated that adults were either reduced or repelled and resulted in 55–71% fewer adults in the sucrose octanoate treatments. Mite numbers were also greatly reduced by the sugar ester and insecticidal soap treatments in comparison with the untreated control ($F = 27.46$; df = 5, 410; $P < 0.0001$). These data support the high degree of miticidal activity for sugar esters found in previous research (Puterka et al. 2003).

During the first field trial, unpublished data of *D. citri* mortality in sucrose octanoate treatments led to the increased concentration of sucrose octanoate tested in the second field trial. Day by treatment interactions were not significant for larval ($F = 0.89$; df = 2, 23; $P < 0.4241$) or pupal mortalities ($F = 1.28$; df = 2, 15; $P < 0.3065$), indicating no response to treatment over time; thus, citrus leafminer mortalities were averaged over time (Table 5). Citrus leafminer mortality was substantially higher ($P > 0.05$) for sucrose octanoate (72%) than for M-Pede (4%). However, neither material produced pupal mortalities.

In trial 2, *D. citri* populations were very high, with a mean of 29 adults per 2-min count, 34 small nymphs, and six large nymphs per 7.6-cm terminal. Day by treatment interactions were not significant, indicating no response to treatment over time; thus, we averaged *D. citri* mortality over time (Table 6). Number of small and large nymphs did not significantly differ for each treatment ($F = 1.5$; df = 6, 29; $P < 0.2136$); therefore, we combined for total nymphal presentation. No significant difference in the number of eggs was detected between treatments during trial 2, and eggs averaged 25 per 7.6-cm terminal. In trial 2, the treatments performed similarly against *D. citri*, producing 89 and 65% nymphal mortalities, 90 and 74% adult reductions, and 91 and 86% mite mortalities for sucrose octanoate and M-Pede, respectively. However, the 8,000 ppm rate of sucrose octanoate used in trial 2 increased adult *D. citri* mortality by ≈20% compared with the lower rates used in trial 1. We found that sucrose octanoate was not phytotoxic at much higher rates (8,000 ppm) than needed to be effective against mites and immature *D. citri*, which is of concern with insecticidal soaps.

Table 5. Field trial 2. Mean number of citrus leafminer (CLM) averaged over sample dates 1 and 4 d after treatment (Trt) in treated and untreated Tangor citrus, St. Lucie County, Fort Pierce, FL

Treatment	Rate[a] (ppm)	Alive CLM larvae	Total CLM larvae	% CLM larval mortality	Alive CLM pupae	Total CLM pupae	% CLM pupae mortality
Sucrose Octanoate	8,000	0.43a	1.57a	72.61b	0.63a	0.63a	0a
M-Pede	9,800	0.93a	0.97a	4.12a	0.59a	0.59a	0a
Untreated		1.53a	1.53a	0a	0.70a	0.70a	0a
Trt* Date		$F = 0.03$	$F = 0.08$	$F = 0.89$	$F = 0.33$	$F = 0.33$	$F = 1.28$
		df = 2, 78	df = 2, 78	df = 2, 23	df = 2, 78	df = 2, 78	df = 2, 15
		$P < 0.9700$	$P < 0.9266$	$P < 0.4241$	$P < 0.7194$	$P < 0.7194$	$P < 0.3065$
Trt		$F = 2.46$	$F = 0.65$	$F = 52.79$	$F = 0.05$	$F = 0.26$	$F = 1.12$
		df = 2, 78	df = 2, 78	df = 2, 23	df = 2, 78	df = 2, 78	df = 2, 15
		$P < 0.0922$	$P < 0.5263$	$P < 0.0001$	$P < 0.9535$	$P < 0.7755$	$P < 0.3522$

Means within columns followed by the same lowercase letter are not significantly different ($P > 0.05$, REGWQ).
Leaves infested with citrus leafminer larvae and pupae from 7.6-cm fresh flush citrus terminals were probed to determine whether insects were dead or alive; total (alive plus dead) reflects all CLM larvae or pupae present in the terminal.
[a] Rate expressed in ppm active ingredient of commercially formulated product.

Table 6. Field trial 2. Mean number of *D. citri* and citrus mite averaged over 1 and 4 d after treatment (Trt) in treated and untreated Tangor citrus, St. Lucie County, Ft. Pierce, FL

Treatment	Rate[a] (ppm)	Egg ± SE[b]	Total nymph ± SE[b] (% mortality)	Adult ± SE[c] (% mortality)	Mites ± SE[b] (% mortality)
Sucrose Octanoate	8000	29.8 ± 12.4a	8.7 ± 2.9b (89)	4.3 ± 0.7b (90)	1.1 ± 0.7b (91)
M-Pede	9800	21.7 ± 7.6a	26.8 ± 6.9b (65)	11.4 ± 1.4b (74)	1.8 ± 0.9b (86)
Untreated		22.1 ± 6.3a	77.6 ± 22.3a	43.6 ± 7.3a	12.7 ± 5.1a
Trt* date		$F = 4.87$	$F = 2.45$	$F = 1.2$	$F = 0.08$
		df = 2, 78	df = 2, 78	df = 2, 78	df = 7, 78
		$P < 0.0102$	$P < 0.0930$	$P < 0.3082$	$P < 0.9240$
Trt		$F = .28$	$F = 7.86$	$F = 33.46$	$F = 4.63$
		df = 2, 78	df = 2, 78	df = 2, 78	df = 2, 78
		$P < 0.7559$	$P < 0.0008$	$P < 0.0001$	$P < 0.0126$

Means within columns followed by the same lowercase letter are not significantly different ($P > 0.05$, REGWQ).

[a] Rate expressed in ppm active ingredient of commercially formulated product.

[b] Mean number of *D. citri* eggs, total small and large nymphs, and mites per 3-in. fresh flush citrus terminal counted with a dissecting microscope.

[c] Mean number of *D. citri* adults per tree visible in a 2-min period.

In trial 3, *D. citri* populations were also very high, which presented a good opportunity to study the repeated application of sucrose octanoate in comparison with insecticidal soaps, M-Pede, and Agri-50 for control of *D. citri*. *D. citri* eggs and total nymphs per 7.6-cm fresh flush terminal averaged 32 and 22, respectively. Adult *D. citri* averaged 34 per 2-min visual tree inspection. Number of small and large nymphs did not significantly differ for each treatment ($F = 1.08$; df = 179, 703; $P < 0.2505$); therefore, size categories for nymphs were combined for total nymph presentation. There were significant day by treatment interactions for *D. citri* nymphs ($F = 10.58$; df = 4, 884; $P < 0.0001$) and adults ($F = 5.08$; df = 4, 533; $P < 0.0005$); thus, data are presented over time (Fig. 1). No significant day by treatment interaction was observed for citrus psylla eggs ($F = 1.22$; df = 4, 884; $P < 0.3027$). Means averaged over sample dates for percentage of egg reduction were highest with M-Pede (56%) followed by Agri-50 (49%) and the high sucrose octanoate rate (43%). The lower rate of sucrose octanoate (3,200 ppm) was significantly different ($P > 0.05$) from the untreated and the other treatments and provided 24% egg reduction. All treatments performed similarly in reducing *D. citri* nymphal and adult populations during the duration of the study ($P > 0.05$). Adult numbers were significantly reduced ($P > 0.05$) by all of the treatments to ≈50% from 6 d after the first treatment applications to 12 d after the second treatment applications. The effect of treatments on adult presence and oviposition was essentially lost 5 d after the second treatment applications. However, *D. citri* nymphs were reduced by 60–80% by all treatments beginning 3 d after initial treatment applications, and this effect lasted for the duration of the study.

These results indicate that sucrose octanoate or the other insecticidal soaps can achieve reasonable control of *D. citri* on citrus. Furthermore, these studies demonstrate that sucrose octanoate and insecticidal soaps can obtain a high level of mite control. Sucrose octanoate may be especially useful in citrus due to its activity against another important pest, *P. citrella*, and the low toxicity of this material to beneficial predators and parasitoids in citrus. Lack of sucrose octanoate rate effect in the field indicates complete coverage is crucial for good efficacy and this is especially true when dealing with contact poisons that lack residual. Our data suggest that both nymphal and adult *D. citri* as well as the mite complex tested would be equally controlled to levels of >90% at the higher concentrations of sucrose octanoate tested and that good cov-

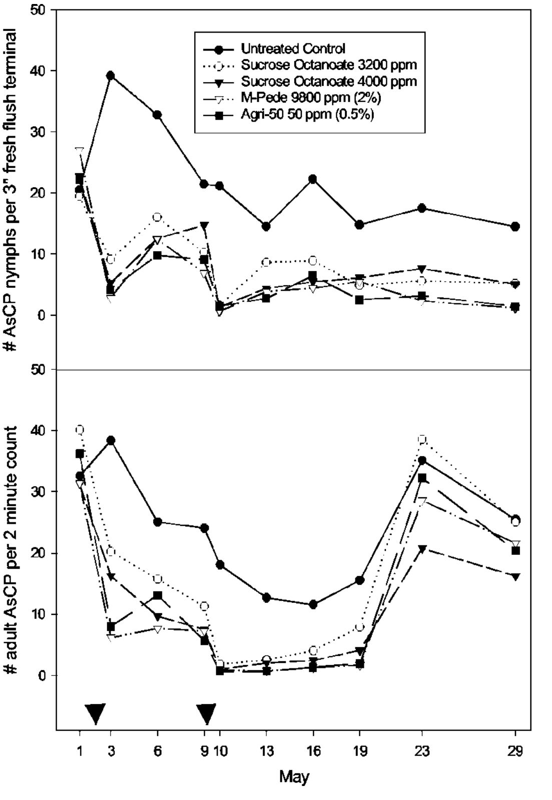

Fig. 1. Field trial 3. Mean number of Asian citrus psylla (AsCP) nymphs and adults in treated and untreated 'Sun shu sha' rootstock citrus trees 1, 4, and 7 DAT1 and 1, 4, 7, 10, 14, and 20 DAT2, St. Lucie County, Fort Pierce, FL. ▼ denotes spray treatment applications 1 (2 May 2003) and 2 (9 May 2003 after insect evaluations).

erage is key to efficacy. Sucrose octanoate has also been found to be relatively nontoxic to a host of beneficial insects typically found in citrus groves (Michaud and McKenzie, 2004) and could prove to be a valuable addition to the list of dwindling products available to the commercial grower.

Acknowledgments

We thank Gary Ouellette and Kathy Moulton for technical assistance; and José X. Chaparro for the use of young 'Ortanique' Tangor citrus trees for the field trials (USDA–ARS, U.S. Horticultural Research Laboratory, Fort Pierce, FL).

References Cited

Aubert, B. 1993. Citrus greening disease, a serious limiting factor for citriculture in Asia and Africa, pp. 134–142. *In* E. Rabe [ed.], Proceedings of the IV World Congress of the International Society of Citrus Nurserymen, Johannesburg: South African Citrus Nurserymen's Association.

Bové, J. M., and M. Garnier. 1994. The phloem-limited bacterium of greening disease of citrus is a member of the α subdivision of the Protoebacteria. Int. J. Syst. Bacteriol. 44: 379–386.

Browning, H. W. 1990. Pests of citrus. *In* D. H. Bennett and J. H. Frank [eds.], Classical biological control in the southern U.S. Southern Co-op Ser. Bull. 355: I-VIII, 1–197.

Caceres, S., and C. C. Childers. 1991. Biology and life tables of *Galendromus helveolus* (Acari: Phytoseiidae) on Florida citrus. Environ. Entomol. 20: 224–229.

Catling, H. D. 1970. Distribution of the psyllid vectors of citrus greening disease, with notes on the biology and bionomics of *Diaphorina citri.* FAO Plant Prot. Bull. 18: 8–15.

Chortyk, O. T., J. G. Pomonis, and A. W. Johnson. 1996. Synthesis and characterizations of insecticidal sucrose esters. J. Agric. Food Chem. 44: 1551–1557.

Clancy, D. W., A. G. Selhime, and M. H. Muma. 1963. Establishment of *Aphytis holoxanthus* as a parasite of Florida red scale in Florida. J. Econ. Entomol. 56: 603–605.

Debach, P., and M. Rose. 1976. Biological control status of woolly whitefly. Citrograph 61: 162–184.

Dowell, J. V., G. E. Fitzpatrick, and J. A. Reinert. 1979. Biological control of citrus blackfly in southern Fla. Environ. Entomol. 8: 595–597.

Glenn, H., and R. M. Baranowski. 1987. Establishment of *Trybliographa daci* (Eucoilidae, Hymenoptera) in Florida. Fla. Entomol. 70: 183.

Gottwald, T. R., B. Aubert, and X. Y, Zhao. 1989. Preliminary analysis of citrus greening (Huanglungbin) epidemics in the People's Republic of China and French Reunion Island. Phytopathology 79: 687–693.

Hart, W. G., R. Selhime, D. P. Harlan, S. J. Ingle, M. Sanchez-Garcia, R. H. Rhode, C. A. Garcia, J. Cabellero, and R. L. Garcia. 1978. The introduction and establishment of parasites of citrus blackfly, *Aleurocanthus woglumi,* in Florida. Entomophaga 23: 361–366.

Hawthorne, D. J., J. A. Shapiro, W. M. Tingey, and M. A. Mutschler. 1992. Trichome-borne and artificially applied acylsugars of wild tomato deter feeding and oviposition of the leafminer *Liriomyza trifolii.* Entomol. Exp. Appl. 65: 65–73.

Knapp, J. L., S. Halbert, R. Lee, M. Hoy, R. Clark, and M. Kesinger. 1998. The Asian citrus pysllid and citrus greening disease. Citrus Industry, Oct. 28–29.

Liu, T. X., and P. A. Stansly. 1995. Toxicity and repellency of some biorational insecticides to *Bemisia argentifolii* on tomato plants. Entomol. Exp. Appl. 74: 137–143.

Liu, T. X., P. A. Stansly, and O. T. Chortyk. 1996. Insecticidal activity of natural and synthetic sugar esters against *Bemesia argentifolii* (Homoptera: Alyrodidae). 89: 1233–1239.

Michaud, J. P., and C. L. McKenzie. 2004. Safety of a novel insecticide, sucrose ocatanoate, to beneficial insects. Fla. Entomol. 87(1): 6–9.

Muma, M. H. 1955. Lady beetles (Coleoptera: Coccinellidae) found on citrus in Florida. Fla. Entomol. 38: 117–124.

Neal, J. W. Jr., J. G. Buta, G. W. Pittarelli, W. R. Lusby, and J. A. Benz. 1994. Novel sucrose esters from *Nicotiana gossei:* effective biorationals against selected horticultural insect pests. J. Econ. Entomol. 87: 1600–1607.

Nguyen, R. 1986. *Encarsia lahorensis* (Howard) a parasite of *Dialeurodes citri* (Ashmead) (Hymenoptera: Aphelinidae). Florida Dep. Agric. Consumer Services Div. Plant Industry, Entomol. Circ. 290: 1–2.

Nguyen, R. 1987. *Encarsia opulenta* (Silvestri) a parasite of *Aleurocanthus woglumi* Ashby (Hymenoptera: Aphelinidae). Florida Dep. Agric. Consumer Services, Div. Plant Industry, Entomol. Circ. 301: 1–2.

Nguyen, R. 1988. *Amitus hesperidum* (Hymenoptera: Platygasteridae), a parasite of the citrus blackfly (*Aleurocanthus woglumi*). Florida Dep. Agric. Consumer Services, Div. Plant Industry, Entomol. Circ. 311: 1–2.

Nguyen, R., and R. I. Sailor. 1979. Colonization of a citrus whitefly parasite, *Prospaltella lahorensis,* in Gainesville, Florida. Fla. Entomol. 62: 59–65.

Parr, J. C., and R. Thurston. 1968. Toxicity of *Nicotiana* and *Petunia* species to larvae of the tobacco hornworm. J. Econ. Entomol. 61: 1525–1531.

Puterka, G. J., and R. F. Severson. 1995. Activity of Sugar esters isolated from the trichomes of *Nicotiana gossei* to pear psylla (Homoptera: Psyllidae). J. Econ. Entomol. 88: 615–619.

Puterka, G. J., W. Farone, T. Palmer, and A. Barrington. 2003. Structure-function relationships affecting the insecticidal and miticidal activity of sugar esters. J. Econ. Entomol. 96: 636–644.

Sailor, R. H., R. E. Brown, B. Munir, and J.C.E. Nickerson. 1984. Dissemination of the citrus whitefly (Homoptera: Aleyrodidae) parasite *Encarsia lahorensis* (Howard) (Hymenoptera: Aphelinidae) and its effectiveness as a control agent in Florida. Bull. Entomol. Soc. Am. 30: 36–39.

SAS Institute. 2000. SAS/STAT guide for personal computers, version 8. SAS Institute, Cary, NC.

Selhime, A. G., M. H. Muma, W. A. Simanton, and C. W. McCoy. 1969. Control of the Florida red scale in Florida with the parasite *Aphytis holoxanthus.* J. Econ. Entomol. 62: 954–955.

Sparks, T. C., and A. Sparks. 1987. Micro Probit. DowElanco, Greenfield, IN.

Tefertiller, K. R., V. C. McKee, and V. G. Perry. 1991. Citrus blackfly in Florida: eradication or bio-control? Agric. Econ 5: 193–209.

Thompson, C. R. 1989. *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), biological control agent for the Caribbean fruit fly. Florida Dep. Agric. Consumer Services, Div. Plant Industry, Entomol. Circ. 325: 1–2.

Received 20 August 2003; accepted 21 January 2004.